EPJ Web of Conferences **203**, 04009 (2019) https://doi.org/10.1051/epjconf/201920304009
EC20

Comparative studies of various types of transmission lines in the frequency range 70 GHz - 1 THz for ITER ECE diagnostic

Ravinder Kumar[1], *S.* Danani[1], *H.K. B.* Pandya[1, 2], *P.* Vaghashiya[1], *V.S.* Udintsev[3], *G.* Taylor[4], *M.E.* Austin[5], *Vinay* Kumar[1, 2]

[1]ITER-India, Institute for Plasma Research, Bhat, Gandhinagar-382428, India
[2]Homi Bhabha National Institute, Anushaktinagar, Mumbai-400094, India
[3]ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France
[4]Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA
[5]Institute for Fusion Studies, University of Texas at Austin, TX 78712, USA

Abstract. In ITER, an Electron Cyclotron Emission (ECE) diagnostic is planned to measure the electron temperature by measuring the cyclotron radiation in the frequency range of 70-1000 GHz. The cyclotron radiation is usually of low power and needs to be transported with low attenuation over a long distance of ~ 43 m, through a suitable transmission system. Pertaining to long distance, the transmission system will consist of straight waveguide sections, miter bends and waveguide joints. Low power, low loss transmission in a broadband frequency range over long distance makes the design of the transmission system challenging. To arrive at a suitable transmission system, attenuation measurements of three types of transmission lines (TLs) have been performed i.e. circular smooth walled, corrugated and dielectric coated waveguide. A polarizing Michelson interferometer based on Martin-Puplett design has been used to measure the spectrum from waveguide set ups and liquid nitrogen has been used as the black body radiation source. The measured spectrum shows atmospheric water vapour absorption lines in all types of TLs. The preliminary measurement shows that the attenuation of smooth walled waveguide is found to be comparable to corrugated waveguide up to ~ 600GHz and better than corrugated waveguide above 600 GHz for the chosen set of experimental conditions. Further, to avoid water absorption lines, a smooth walled TL is evacuated up to rough vacuum (~10^{-2}mbar) and it was observed that the attenuation is decreased and overall transmission is improved.

1 Introduction

In ITER, the electron cyclotron emission (ECE) diagnostic [1] will be used to determine the plasma electron temperature, plasma energy, ECE radiated power and runaway electrons in the frequency range 70 GHz - 1 THz by measuring the cyclotron radiation. The typical ECE system consists of front end optics including in-situ calibration sources, a set of transmission lines (TLs), and ECE radiation measurement instruments like radiometers and Michelson interferometers. However, one of the challenging requirements for the ITER ECE diagnostic is achieving low attenuation in the long TL (~43m length) for the broad frequency range. This is particularly challenging because of the low power (~ few nW) thermal radiation emitted from the in-situ calibration sources located in the port plug which needs to be measured by the ECE instruments that are located nearly ~ 43 m away in the diagnostic building. The TL will consist of straight waveguide sections, miter bends and waveguide joints. The attenuation of the TL will play an important role in determining the accuracy of measurements performed. Various investigations are underway to find a suitable TL system meeting this crucial requirement. Here, we have studied the performance of three types of circular TLs viz. smooth walled [2], corrugated [3] and dielectric coated circular waveguides. In addition, various TL components like 90^{o} miter bends, waveguide joints, pump out units and straight waveguide sections are also characterized. The attenuation of TLs has been measured in the frequency range 70 GHz - 1 THz using a liquid-nitrogen-cooled 77 K black body source and Fourier-transform-based Michelson interferometer, and the attenuation is determined using the cutback technique. It is well known that the water vapour present in the air attenuates the millimetre waves at the water vapour absorption lines. In order to avoid absorption of the millimeter waves, the smooth walled TL system is evacuated and measurements are repeated. The TL performance is then compared in air and vacuum. The details of TL components, experimental set up and the results of the comparative studies of attenuation in three types of TLs will be discussed in this paper.

2 Transmission line and experimental set-up

Three types of circular TLs – smooth walled of inner diameter (ID) 72mm; corrugated, ID 88.9 mm; and dielectric coated, ID 69.9 mm, were characterized by measuring their attenuation in the broadband millimeter wave frequency range 70 GHz - 1THz. A broadband prototype Fourier Transform Spectrometer (70-1000

* Corresponding author: **ravinder.kumar@iter-india.org**

GHz) [4] has already been developed as per ITER ECE requirements and this FTS is used for all the prototype TL measurements. The FTS is Martin-Puplett polarizing type with linear scanning mirror to provide path length change of 15 mm resulting in a vacuum frequency resolution ~ 10 GHz and temporal resolution of 10 ms. To the best of our knowledge, all currently operating ECE interferometers are operated in air, and so this prototype FTS serves as a distinctive broadband measurement facility in vacuum, required for characterising the prototype TLs for ITER. Eccosorb [5] at liquid nitrogen temperature is used as a millimeter wave black body source for these measurements. The experimental set-up consists of the millimetre wave black body source, the FTS and the TL as shown in Figures 1 and 2. The typical TL consists of straight waveguide sections, miter bends and waveguide joints.

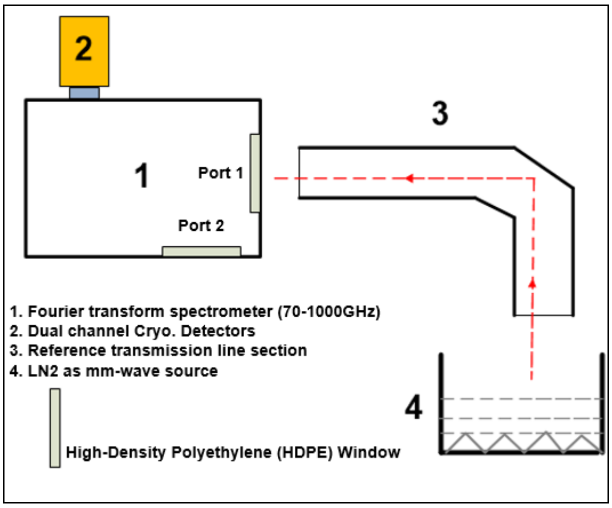

Fig. 1: Schematic of experimental set-up

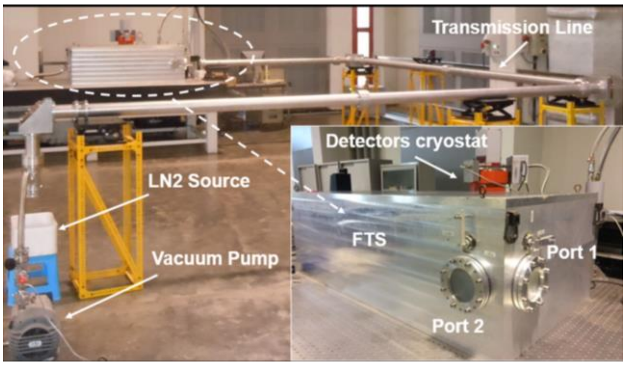

Fig.2: Experimental set-up for TL attenuation measurement

3 Results and Discussions

In this section, first the spectra measured for various transmission lines are shown. Then using the spectra, the transmission attenuation for different waveguides is derived and they are compared. As per availability of waveguide components, the attenuation is measured for 8 m of smooth walled TL, 4 m of dielectric coated and 1 m of corrugated waveguide.

3.1 TL measurements in air

Circular Smooth walled waveguide

Figure 3 shows the measured spectra for different lengths of smooth walled circular waveguide. There are water vapour absorption lines at 380, 448, 552, 752, 916 and 988 GHz. The broadness and depth of the lines increases with the length of the TL section.

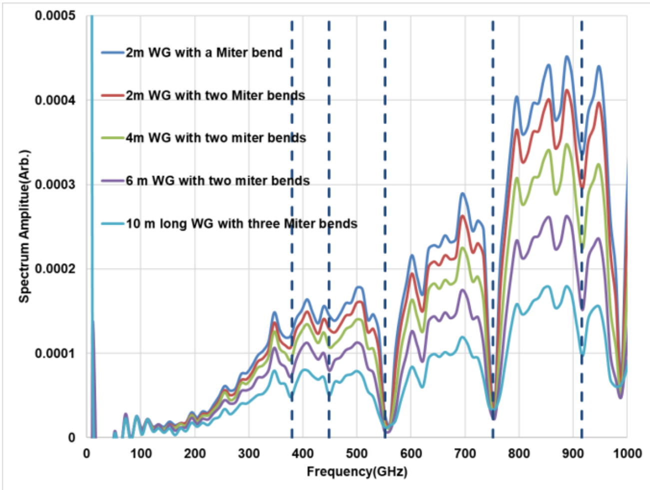

Fig. 3: Measured spectra for various TL sections

Corresponding to different TL lengths, the transmission attenuation is derived as shown in Figure 4.

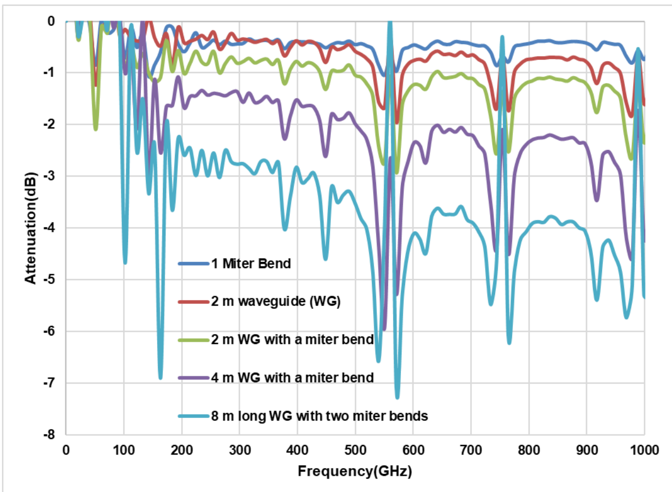

Fig. 4: Measured attenuation for various length of the smooth walled waveguide sections

Similarly, experiments were performed to measure the transmission attenuation for the dielectric coated and circular corrugated waveguides and the results are shown Figures 5 and 6 below.

Circular dielectric coated guide

The inner surface of the metallic waveguides is coated with optimal thickness of dielectric to minimize the transmission loss. The transmission loss is minimized as dielectric coated waveguide supports the hybrid mode, which has maximum power at the centre of waveguide and the electric fields are substantially vanished at the walls of the waveguide. Therefore, the dielectric thickness has to be chosen in such a way that the broadband millimetre wave transmits with a low loss in the desired frequency range.

The transmission attenuation is measured for 2 meters and 4 meters with 1 miter bend in a dielectric coated waveguide, and it is show in Figure 5

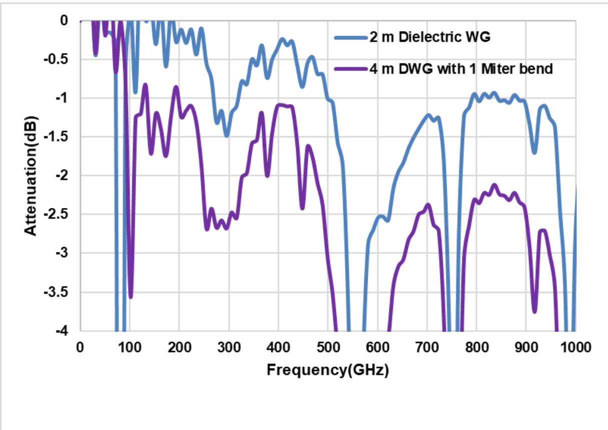

Fig. 5: Measured attenuation for various dielectric coated waveguide sections

Circular Corrugated waveguide

The 88.9 mm circular corrugated waveguide with a Bragg frequency of ~ 136 GHz is used for measuring the transmission attenuation in broadband millimetre wave frequency range 70 - 1000 GHz. The attenuation is measured in a 1-meter length waveguide section including a 90-degree bend, and is shown in Figure 6.

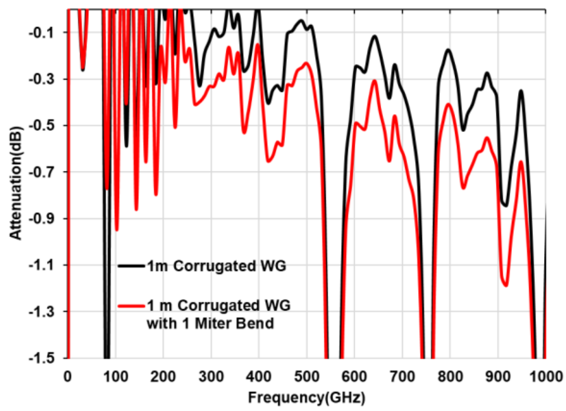

Fig. 6: Measured attenuation for circular corrugated Waveguide sections

3.2 Attenuation Comparisons

The transmission attenuation per unit length for each type of waveguide is derived and compared in Figure 7. It is observed that smooth walled circular waveguide has less attenuation at high frequency compared to Corrugated & dielectric coated waveguide.

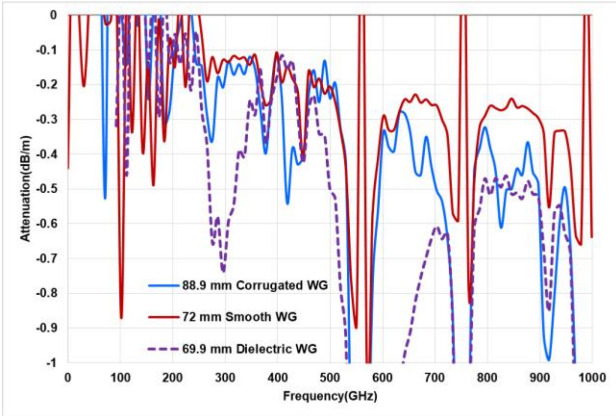

Fig. 7: Comparison of per meter transmission attenuation for various TLs

3.3 TL Measurements in a low Vacuum

In order to avoid the water absorption lines, the smooth walled TL is evacuated up to 10^{-2} mbar. The spectrum of a 10 m TL including 3 miter bends is measured in vacuum and compared with that of air TL. There is atmospheric path length i.e. ~ 550 mm in the transmission path as the millimeter wave source is not vacuum compatible. The comparison of measured spectra are shown in Figure 8. It is observed that there is some level of continuum absorption of the radiation in this frequency range by atmospheric gases.

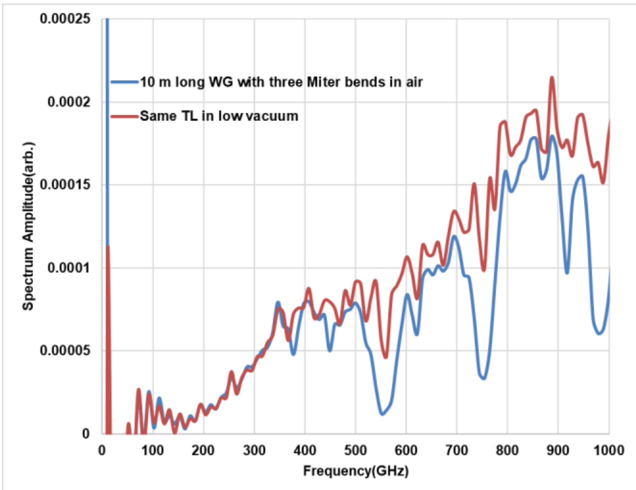

Fig. 8: Spectra of 10 m smooth TL in air and vacuum medium

The transmission attenuation is compared for the two cases and the preliminary result show that the attenuation is reduced in the case of evacuated TL and overall transmission is also improved.

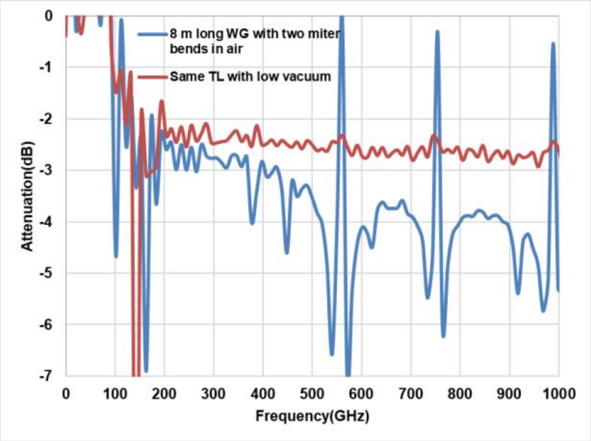

Fig. 9: Comparison of transmission attenuation in air and low vacuum

4 Conclusions

The transmission attenuations have been measured in three types of waveguides viz. circular smooth walled, corrugated and dielectric coated, using an FTS operating in the frequency range 70-1000 GHz. For each type of TL, attenuation is measured in air for a unit length of TL and compared. The preliminary measurements show that the attenuation of smooth walled waveguide is comparable to the corrugated waveguide up to ~ 600 GHz and it performed better as compared to corrugated guide above 600 GHz for the chosen set of experimental conditions as described in section 2. Water vapour absorption lines are found at certain frequencies with TLs operating in air. In case of evacuated TL, the attenuation is decreased and overall transmission is improved. It is also inferred from vacuum measurements that there is some level of continuum absorption of the radiation in this frequency range by atmospheric gases.

Acknowledgement

The author would like to thank Dr. W. Kasparek, University of Stuttgart, Stuttgart, Germany for providing dielectric coated waveguides used in the attenuation measurements.

References

1. V. S. Udintsev et al., "Progress in ITER ECE Diagnostic Design and integration," in this workshop, Griefswald, 2018.
2. H. B. Pandya, M.E. Austin, R.F. Eliis, Rev. Sci. Instrum., vol. 84, no. 103505, 2013.

3. Ravinder Kumar et al., "Fabrication and characterization of TL for ITER ECE Diagnostics," in National Symposium on Plasma Science & Technology (http://www.ipr.res.in/plasma-2017/), Gandhinagar, 2017.
4. H. B. Pandya et al., "Characterization of the Prototype Michelson Interferometer for the ITER ECE Diagnostic system," in National Symposium on Plasma Science & Technology, Gandhinagar, 2017.
5. http://www.eccosorb.com/

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.